TEMPERATURE FLUCTUATIONS NEAR THE AIR-SEA INTERFACE

by

John Gabriel McMillan

UNITED STATES
NAVAL POSTGRADUATE SCHOOL

THESIS

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June 1968

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TEMPERATURE FLUCTUATIONS

NEAR THE AIR-SEA INTERFACE

by

John Gabriel McMillan
Lieutenant Commander, United States Navy
B. S., Naval Academy, 1958

Submitted in partial fulfillment of the
requirements for the degree of

MASTER OF SCIENCE IN OCEANOGRAPHY

from the

NAVAL POSTGRADUATE SCHOOL

June 1968

ABSTRACT

The design, construction and calibration of suitable instrumentation for measuring temperature fluctuations within a few centimeters of the sea surface, surface wave variations, and wind velocity are discussed. Small bead-in-glass thermistors mounted at 2.5 and 5 centimeters above the water surface were used to measure temperature variations under varying wind conditions and spectral densities computed on a digital computer. Spectra, co-spectra and coherence squares from 0 to 5 Hz are presented.

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1. Introduction

The energy exchanges between the atmosphere and the oceans are the driving force for a thermodynamic and mechanical system which encompasses the fluid portions of the earth. The atmosphere derives energy from the sea in the form of sensible and latent heat and in turn, provides mechanical energy for oceanic circulations. Small-scale processes, such as convection and local wind fields, are also direct results of these energy exchanges, and the ability to accurately measure energy fluxes at any level over the sea would permit one to predict the growth and decay of such processes.

There are generally four forms of air-sea energy exchange that one may consider:

1. Electromagnetic radiation
2. Convection and conduction of sensible heat
3. Convection and diffusion of latent heat in the form of water vapor
4. Vertical exchange of mechanical energy.

In investigating the flux of any of these forms of energy, one must measure directly certain quantities. For heat flux, the appropriate equations are: $E_s = \rho C_p \overline{Tw}$ and $E_l = \rho_w \overline{Lw}$, where E_s is the sensible heat flux, E_l is the latent heat flux, ρ and ρ_w are the densities of air and water respectively, C_p is the specific heat of air at constant pressure, L is the latent heat of evaporation (or condensation), T is the temperature and w is the vertical component of the wind velocity. Then, to measure the heat fluxes, one must be able to measure temperature, vapor pressure, and wind velocity at any desired level. Since waves on the water surface interact with the wind field (which carries the scalar temperature field), the surface wave field may also have an effect on heat flux.

As a preliminary step in the determination of heat flux, methods of measuring variations of temperature, wind velocity, and water surface displacement on the smallest possible time and space scales must be devised and tested. This study was made to investigate some of the possible approaches to these measurements close to the air-sea interface and had as its objectives:

1. The design of a suitable sensor system for measuring the temperature fluctuations within a few centimeters of the sea surface, the wave field at the same point, and the downstream wind velocity at a suitable level above the surface.
2. The continuous recording of these three measurements in a form suitable for digital analysis.
3. The analysis of the records to determine the appropriate spectra and the relation, if any, between the air-temperature variations and the water-surface height under varying wind conditions.

2. Design of the Measurement System

A system to measure small temperature variations requires a temperature sensor that is durable, inexpensive, and that has a sufficiently small response time to record fluctuations at frequencies of about 10 Hz. A small bead thermistor was used and although thermistor time constants are generally large compared to, say, a platinum resistance thermometer, it appeared that they were sufficiently small for this investigation. A Victory Engineering Corporation bead-in-glass thermistor, model 32A49, was used. The manufacturer's specifications for this unit are: a nominal diameter of 0.013", a time constant (τ) of 1.0 seconds in still air, a power dissipation constant of 0.10 mw/°C, and a continuous operational range of -50°C to 300°C. The zero-power resistance at 25°C is 2500Ω $\pm$ 25%, and the resistance-temperature ratios are 5.6 for R_o at 0°C/R_o at 50°C, and 14.6 for R_o at 25°C/R_o at 125°C. However, over the range of temperatures encountered in this study (about 5°C), the resistance-temperature curve is essentially linear (Figure 7).

Two of these thermistors were mounted on a guided styrofoam float, at about 2.5 and 5 cm above the water surface, as shown in Figure 2. A variety of float designs were tested for response to surface waves. The one used in the field was a hemisphere of about 2.5 cm diameter. In wave tank tests, movies showed the float to follow the waves quite well, although, of course, it tended to act as a filter for most waves smaller than the diameter of the float.

To measure the water-surface fluctuations, a resistance wave gauge was mounted as close as possible to the thermistors. This gauge consists of a pair of 0.01" diameter stainless-steel wires, about 25 cm in length and positioned some 3 cm apart (Figure 1). A 5 volt, 20 Hz power source was used to avoid electrolysis, and the signal output from the bridge was fed through a full-wave rectifier.

Wind velocity was measured with a Casella sensitive cup anemometer, mounted approximately one-half meter above the water. The anemometer has a digital counter to record wind velocity and was used to determine mean wind speeds over time intervals of 10 to 30 seconds.

The wave gauge and thermistors were installed as one leg of separate Wheatstone bridges and the outputs recorded on Mosley 7100B strip recorders. This recorder has individual DC amplifiers for each channel with maximum amplification providing a 5-mv per 10-inch scale. The recorders were operated at 0.5 inches-per-second chart speed for all measurements. The bridge and rectifier circuitry for each instrument is shown in Figures 3 and 4, and a block diagram of the basic data-collection system is given in Figure 5.

The platform for field mounting the sensors is shown installed for measurements in Figure 6. The transmission lines for signal output are shielded, two-core telemetry cables with low-loss characteristics.

3. Instrument Calibration and Observation Techniques

The thermistors were calibrated by varying the temperature of a water bath and plotting the resulting resistance change for each temperature increment. The results are presented in Figure 8. Since this curve was essentially the same for each individual thermistor, it was assumed that minor differences in slope could be ignored. Before field measurements, the bridges were balanced in the laboratory at a temperature close to that expected in the field. Each recorder channel was calibrated to a scale of 1°C per inch and for equal sensitivity in each channel. The entire system was then tested with a known temperature change with the telemetry cables installed. The response time of the system was estimated by running the recorder at its maximum chart speed (2 inches per second) and recording a known temperature change. The time for 63% of the change (one time constant) was then measured directly from the record. Since the temperature changes were induced by adding water of a different temperature to the bath, the actual temperature change was not instantaneous, and the estimate of 80 msec is perhaps too large. It is, however, a good indication that a flat response to 10 Hz is a conservative estimate. This response will be somewhat less in moving air, and a response of 5 Hz was considered to be the upper limit for a flat response for this study.

The wave gauge was calibrated in a wave tank to find the required immersion for maximum signal amplitude. The smaller the immersion, the greater the signal amplitude. Above a wave amplitude of about 5 cm, the output became slightly distorted due to the non-linearity of the gauge system. Again, the range of measurements in this study was sufficiently small that the response could be considered linear. The output of the full-wave rectifier was compared with a common generated signal of 0 to 10 Hz and showed an undistorted output over this range.

The Casella anemometer was not calibrated. The manufacturer's conversion curves for counter readings to velocities were assumed to be accurate.

The field observations were made during the months of April and May, 1968 at Roberts Lake, Seaside, California. This small lake is approximately one-half mile inland from Monterey Bay and is about 450 yards long and 200 yards wide. Between the bay and the lake are a series of sand dunes about 25 to 30 feet high which end about 150 yards from the lake. There is no other obstruction to air flow in this area to seaward and the winds are essentially those present over Monterey Bay. The available unrestricted fetch at the measurement site is between 75 and 400 yards, depending on the wind direction. Most of the data was taken with a fetch of from 100 to 300 yards. The platform was placed in about three feet of water, 25 to 30 feet from shore, and the signals were transmitted to the recording equipment with the low-loss cables.

Measurements were made on six occasions, the first three with only a single thermistor mounted at 2.5 cm. The lengths of the recordings were between 3 and 5 minutes, with mean measured winds from 2.4 to 8 meters per second. The significant wave heights were between 2 and 4 cm, with periods of from 1.2 to 1.8 seconds and lengths of from 10 to 15 cm. One representative record of the single-probe measurements and one of the dual-probe measurements were analyzed. A portion of a computer drawn record of dual-probe data is shown in Figure 8.

4. Analysis

In previous air-temperature measurements (Pond et al, 1966), a substantial portion of the spectral "energy" was concentrated in the region below 10 Hz. Since 5 Hz was considered to be near the upper limit of the flat response of the thermistor, the analysis of the data was restricted to the range of frequencies from 0 to 5 Hz. As the data was recorded in a graphic form, the conversion to digital form required a manual interpretation at intervals of 0.05" and 0.025°C. This process certainly introduced some noise into the record (in addition to that generated by the electronics in the system), but this was unavoidable. The ensuing analysis showed this noise to be negligible.

Since the temperature fluctuations at the air-sea interface are felt to be essentially random and stationary, it is appropriate to analyze the data by computing power spectra. This method of analysis is the basis of an existing FORTRAN IV program in the library of the N.P.G.S. computer library, PROGRAM BLACKY (Table I) This program computes smoothed power spectral estimates from the Fourier transform of the covariance for a given frequency bandwidth.

In analyzing any continuous process using discrete points, the problem of aliasing is encountered. For this study, it was assumed that little energy existed above 5 Hz. PROGRAM BLACKY also provided a filter by running a weighted average for three consecutive points of the record. This would reduce the possibility of folding and also remove most of the high frequency noise.

In order to confirm the results of PROGRAM BLACKY, and to obtain a graphic display of the spectra, the data was also run in PROGRAM BIMED 02T, an autocovariance and power spectrum program of the Health Science Facility, UCLA. The records were also analyzed for means, density and cumulative distributions.

5. Results and Conclusions

The data was processed for smoothed estimates of spectral density from 0 to 5 Hz at an interval of 0.025 cycles. The record was filtered by means of a Hanning lag window of the form:

$$D_r = 0.5(1 + \cos \frac{\pi r}{m})$$

where D_r is the weighting function, m the number of lags for the record, and r is an incremental index of m. The weights for this analysis were 0.25, 0.50 for the three consecutive points. The first and last points were computed with weights of $0.5\ x_o + 0.5\ x_1$ and $0.5\ x_{m-1} + 0.5\ x_m$. This low-pass filter effectively removed the high frequency noise of the record. Since little energy was felt to exist at high frequencies, the loss of this portion of the signal was considered to be insignificant.

The smoothed spectral estimates for the temperature variations are presented in Figures 9 and 10, and the corresponding wave amplitude spectra in Figure 11. A co-spectrum for the dual-probe temperatures is presented in Figure 12. The values from which these plots were taken are given in Tables II and III. The spectra are presented as $\log_{10}\Psi(f)$ versus $\log_{10}(f)$, with $\Psi(f)$ in units of $(°C)^2$sec. The spectrum is defined such that

$$\int_0^\infty \Psi(f)df = \overline{\theta^2}$$

where θ is the temperature variation (Batchelor, 1959). The wave amplitude spectrum, $\emptyset(f)$, is defined similarly, with units of cm^2sec. Since Taylor's hypothesis of "frozen turbulence" (Taylor, 1938), is not valid for a region of shear flow, the relation

$$k = \frac{2\pi f}{U}$$

where k is the wave number, f the frequency, and U the mean wind velocity, was not used and the spectra are presented in terms of frequency rather than wave number.

The total "energy" was estimated in two ways in PROGRAM BIMED 02T; (1) by computing the variance, and (2) by integrating the power spectrum with the trapezoidal rule. The ratio of (1)/(2) gives the fraction of the total energy in the computed spectra. The following table gives the individual values and the resulting ratios.

$\Psi(f)/\emptyset(f)$	Check sum of PSD	Energy by Trap. rule	Diff.	Ratio (1)/(2)
Temp. 2.5 cm (Single-probe	1.1057844	1.1058750	-9.06×10^{-5}	1.00
Temp. 2.5 cm (Dual-probe)	0.2300338	0.2300585	2.47×10^{-5}	0.99
Temp. 5 cm (Dual-probe)	0.3806309	0.3806635	3.27×10^{-5}	0.99
Wave Amplitude (Single-probe)	2.5749149	2.5751486	2.337×10^{-4}	0.99
Wave Amplitude (Dual-probe)	0.2900739	2.2900738	1.00×10^{-7}	1.00

The high percentage of energy in the computed spectra indicates that there is little energy above 5 Hz and there was negligible energy folding from higher frequencies.

Confidence limits for the spectral estimates were calculated for an 80% interval. For the analyzed record length of 120 seconds, a sampling interval of 0.1 seconds, and a correlation lag value of 200, the 80% limits are;

$0.65\,\Psi(f) \leq \Psi(f) \leq 1.91\,\Psi(f)$. The computation of these limits is presented in Appendix A.

Coupling, between the surface waves and the temperature fluctuations at fixed heights above the undulating surface, does not appear to exist, even at the higher wind speeds. The coherence square function is

$$\gamma^2_{xy}(f) = \frac{\left|G_{xy}(f)\right|^2}{G_x(f)\,G_y(f)}$$

where $G_{xy}(f)$ is the co-spectral density function and $G_x(f)$ and $G_y(f)$ are the individual spectral density functions (Bendat and Piersol, 1966). The coherence square for the temperature and wave spectra (Table II) shows virtually no correlation between these quantities. Since the temperature measurements were taken at a height that remained constant with respect to the water surface, this lack of correlation suggests that the temperature structure at this level is not affected by the passing wave surface. In contrast, spectral densities for temperature measurements taken at a fixed height above mean sea level have shown periodic maxima at the same frequencies as wave amplitude spectral maxima (Makova, 1963). A comparison of measurements taken at a fixed height above the surface and simultaneously at a fixed height above mean sea level would be useful in further studies of this problem.

The one-dimensional spectra of temperature fluctuations plotted on a log-log scale (Figures 9 and 10) show a $-^5/_3$ slope for frequencies above 0.2 Hz. This slope has also been found for temperature measurements taken with a platinum resistance thermometer at heights of one meter and greater (Pond et al, 1966). Since the inequality, $kz \gg 4.5$ does not hold near 0.2 Hz, this result indicates that a relation of the form

$$\Psi(f) = C_1 A e_\theta e^{-1/3} k^{-5/3}$$

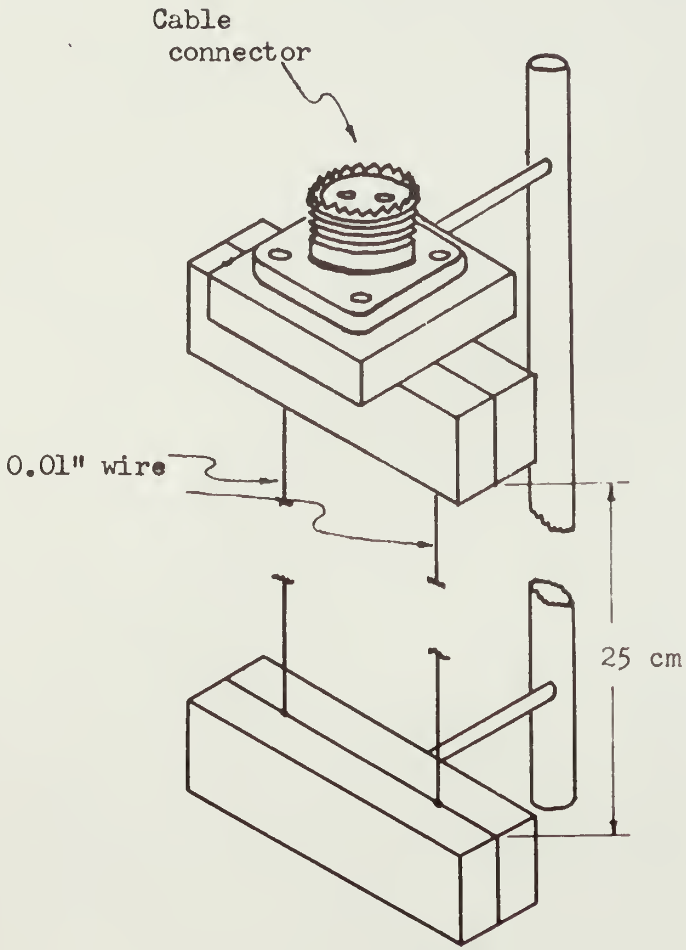
(Batchelor, 1959) is valid for anomalously large scales. (Here, C_1 is a conversion constant to relate the spectrum to frequency rather than wave number, e_θ is the scalar dissipation, e is the energy dissipation, and A is a universal constant.) This result was also found by Pond et al (1966). The high values of the water-wave spectra below 0.05 Hz are not readily explainable, but may be related to a periodic pile-up of water at the leeward end of the fetch, where the measurements were taken. In a small lake, such as was used in this study, periodic gusts can easily set up a seiche.

An examination of the coherence square for the dual-probe temperatures shows a high degree of correlation over the entire spectrum (Table III). This, together with the similarity in the amplitudes of the fluctuations as seen in Figure 8, is somewhat surprising in view of the 5-cm probe being twice as far from the water as the lower probe. The mean temperatures for the dual-probe record are; 14.26°C at 2.5 cm and 14.04°C at 5 cm. The mean air temperature as recorded at approximately 5 cm above the water with a mercury thermometer was 14.0°C and the water temperature at the surface was 20.8°C. Clearly, the air near the water was highly unstable, and it appears that the greatest air temperature gradient occurs below 2.5 cm.

The results of this study indicate that the data collection system used for obtaining temperatures and wave records was reasonably accurate and that additional work should be done to reduce the level at which the temperatures can be taken.

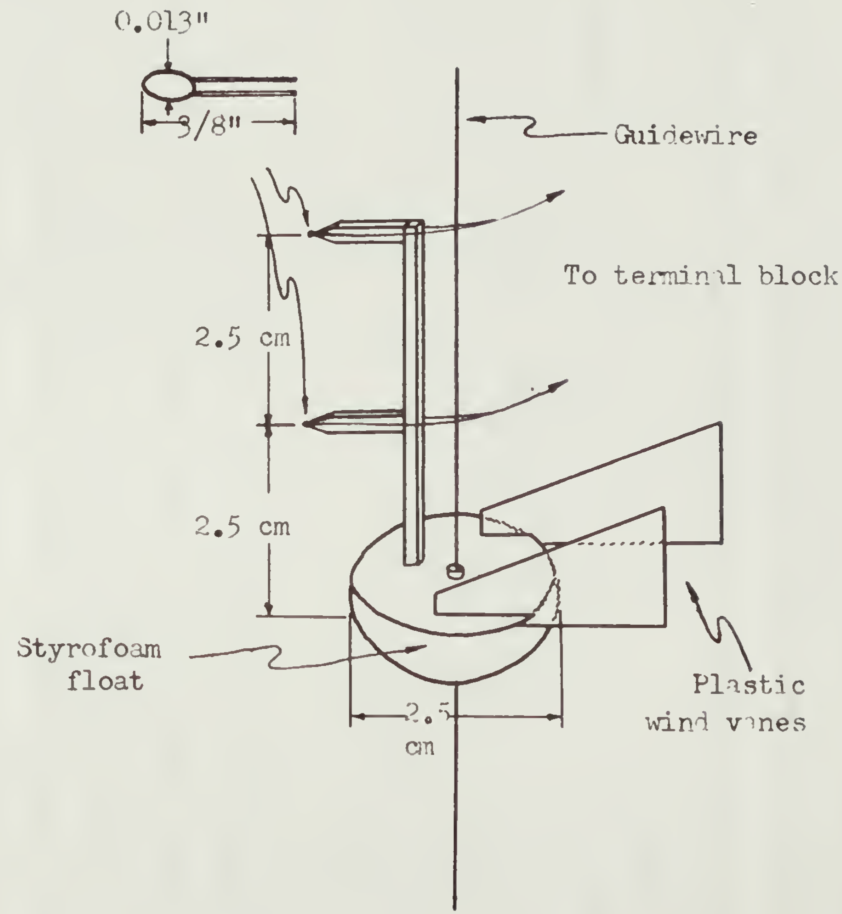
6. Recommendations for Future Studies

Further work in this field should include a continuous record of the wind field, additional thermistor probes at lower levels (and at least one below the water surface), a simultaneous record of temperature at a fixed height above mean water level, and the development of a sensor mounting that will not interfere with the wave field, such as a servo-follower system.



Wave Gauge

Figure 1.



Float and Probe Mounting

Figure 2.

Thermistor Bridge
(One per probe)

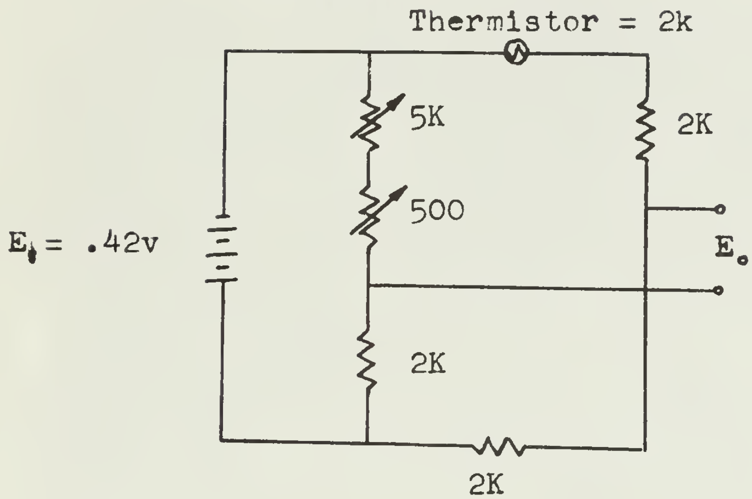


Figure 3

Wave Guage Bridge and Rectifier

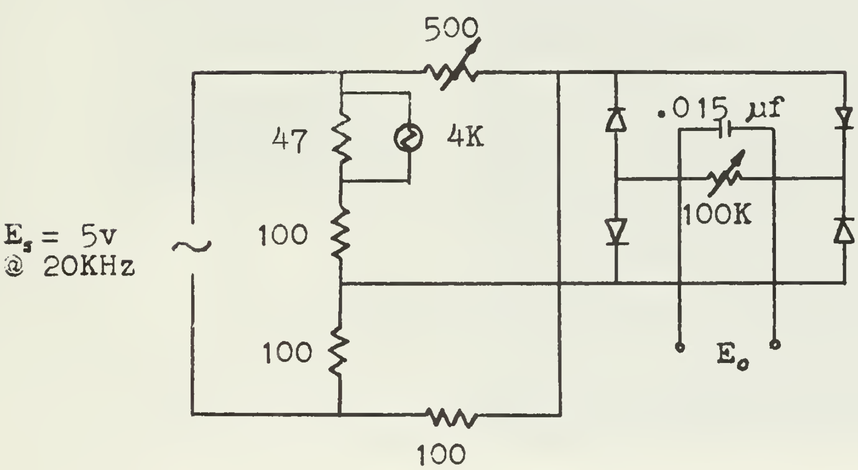


Figure 4

Block Diagram
of
Data Collection System

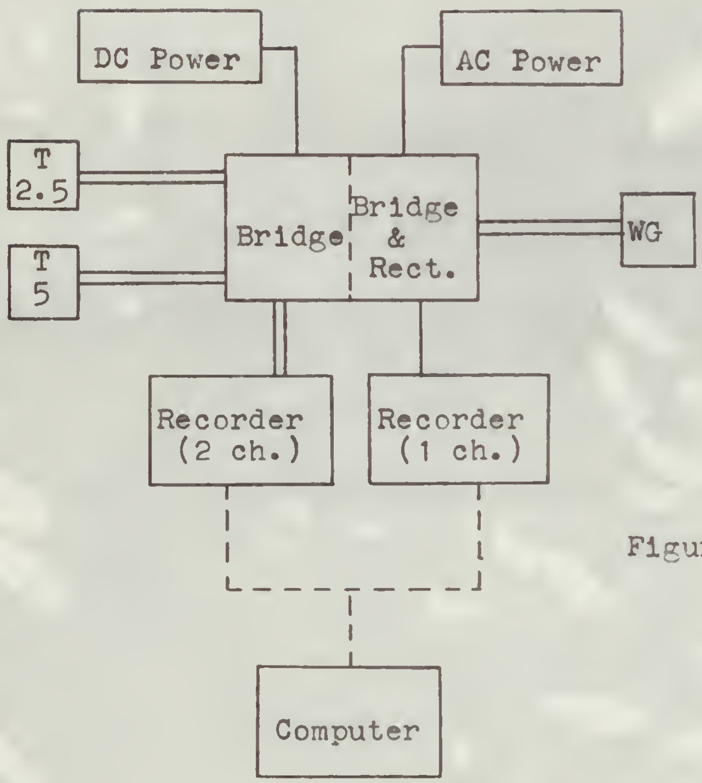


Figure 5

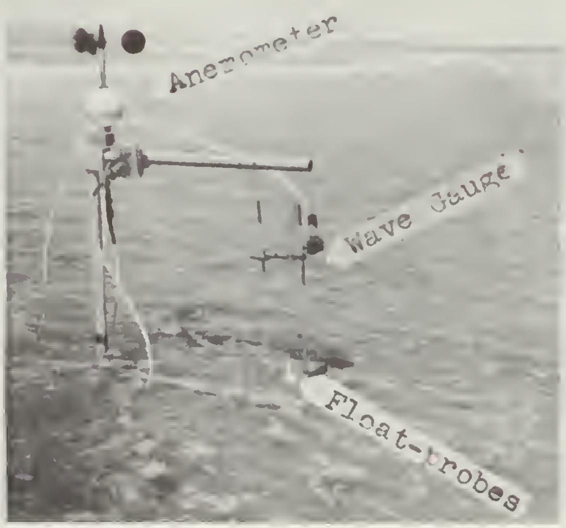
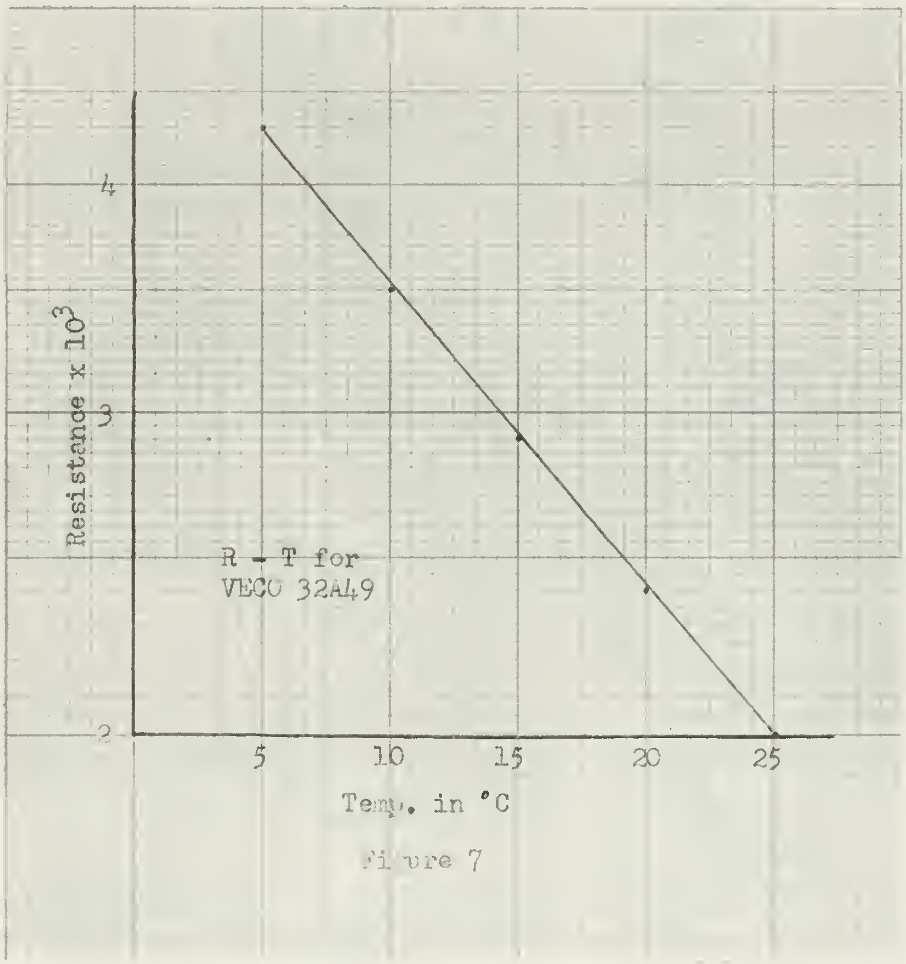


Figure 6
Sensor Platform



Resistance-Temperature Curve
VECO 32A49 Thermistor

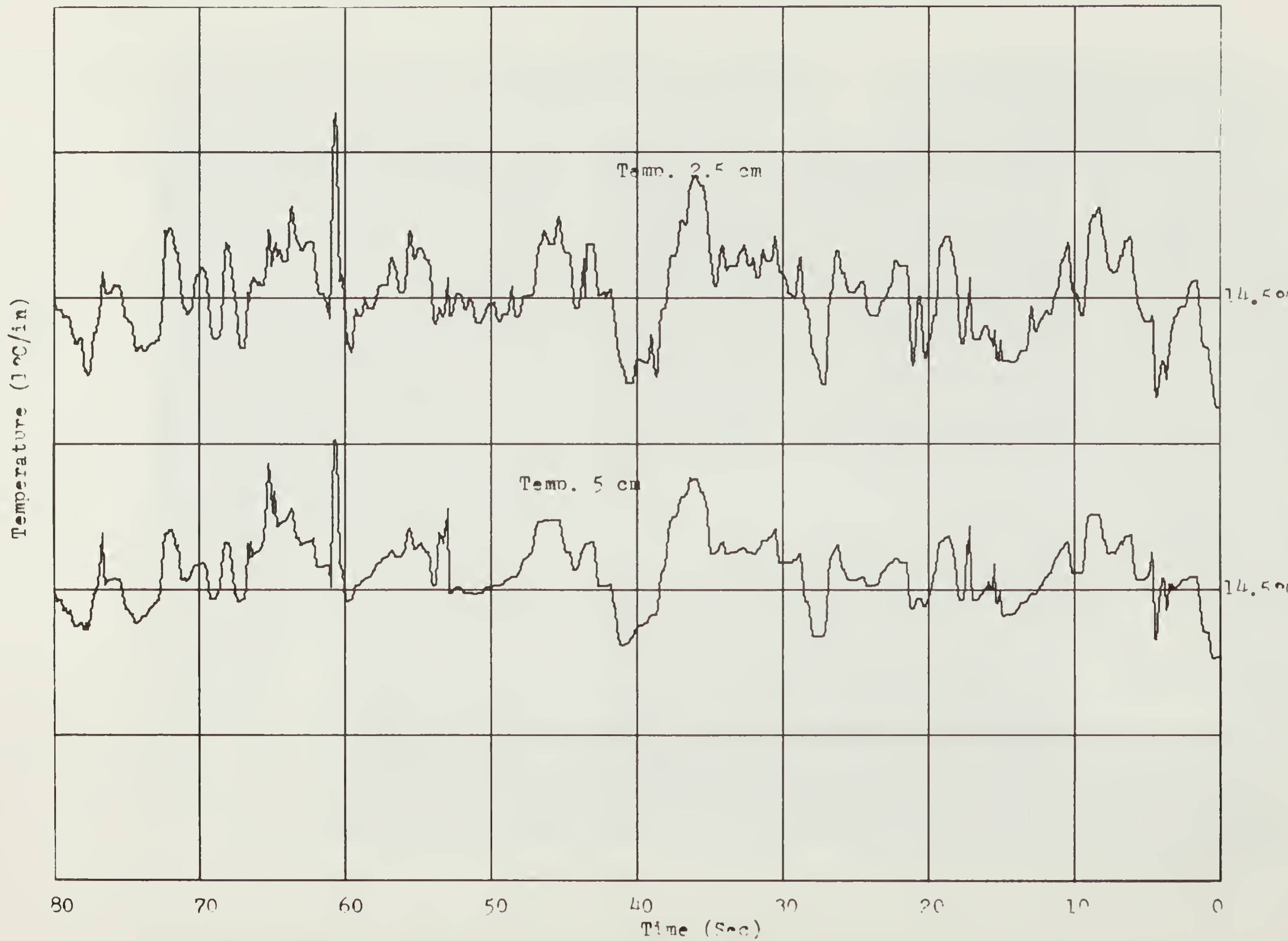


Figure 8. Computer Drawn Temperature Record (Dual-probe)

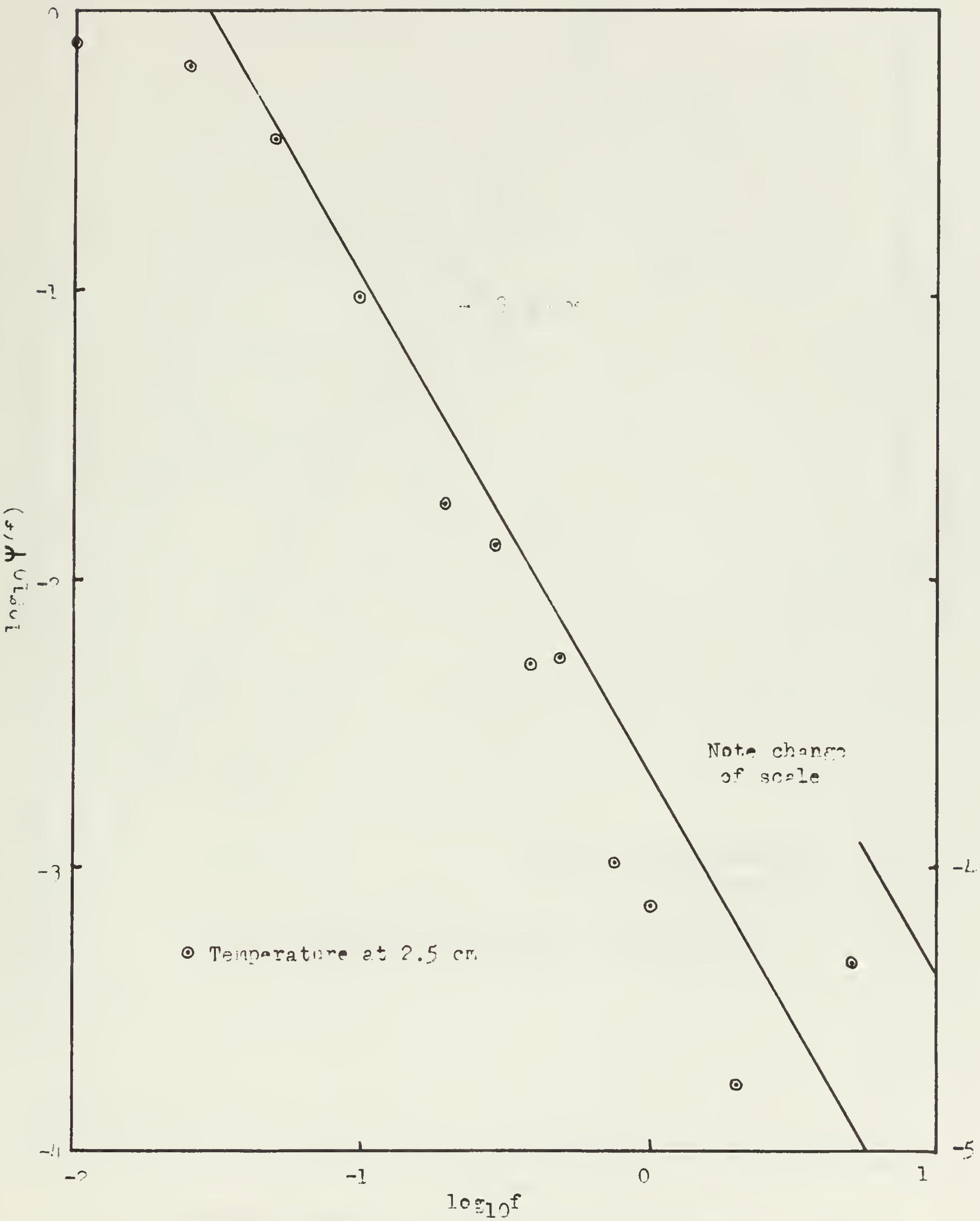


Figure 9. Smoothed Power Spectrum, Single-probe Temperature

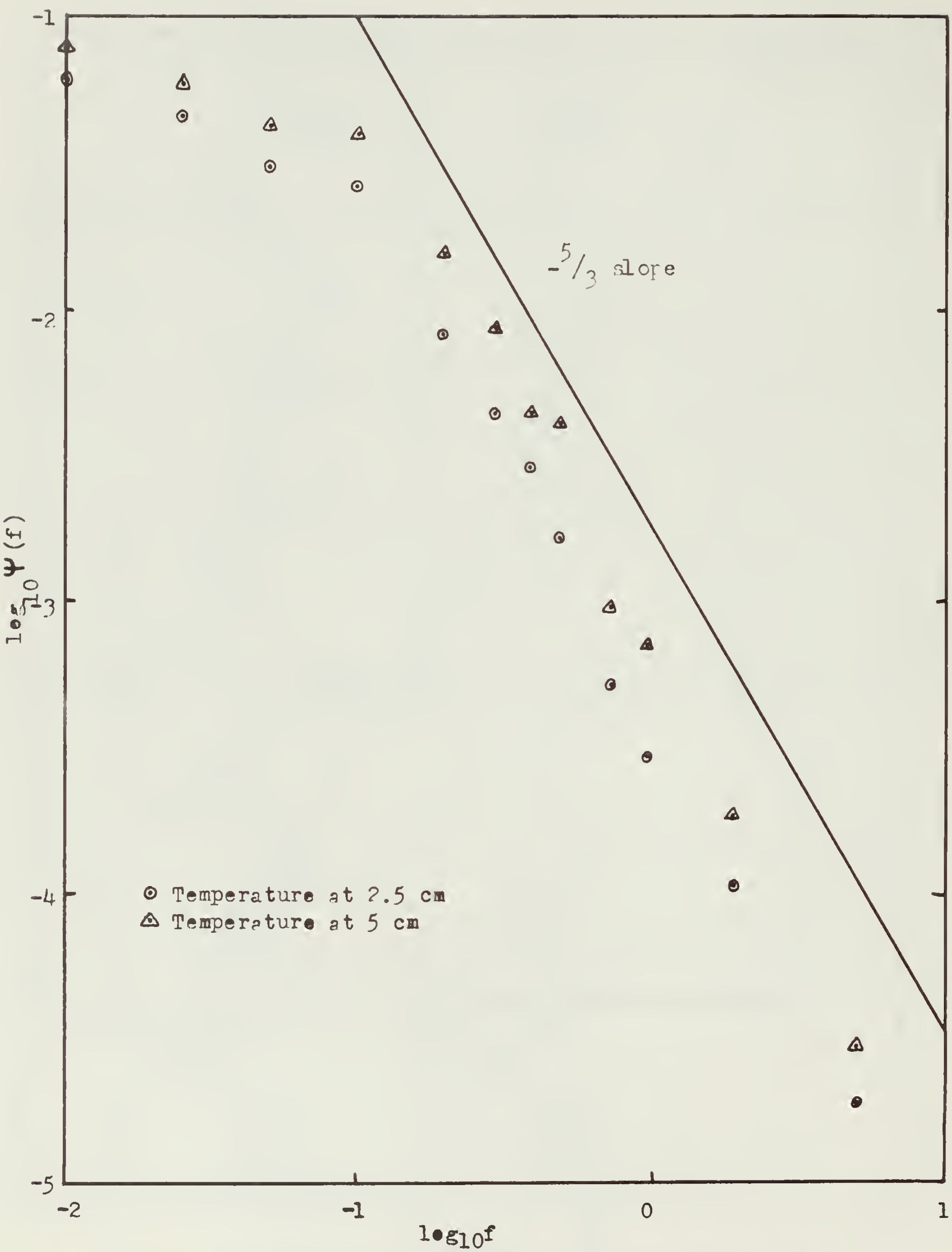


Figure 10. Smoothed Power Spectrum, Dual-probe Temperature

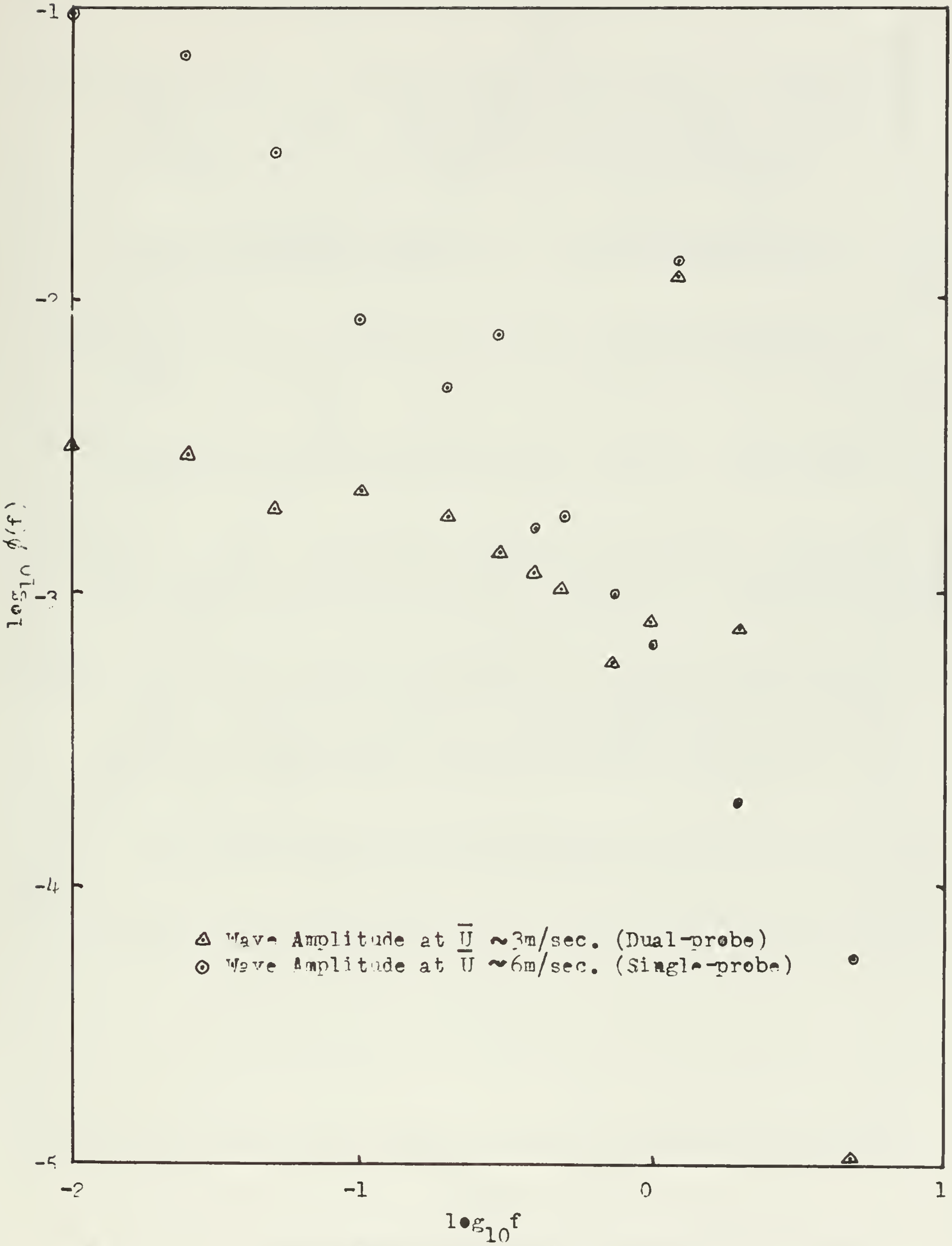


Figure 11. Smoothed Power Spectrum, Wave Amplitude

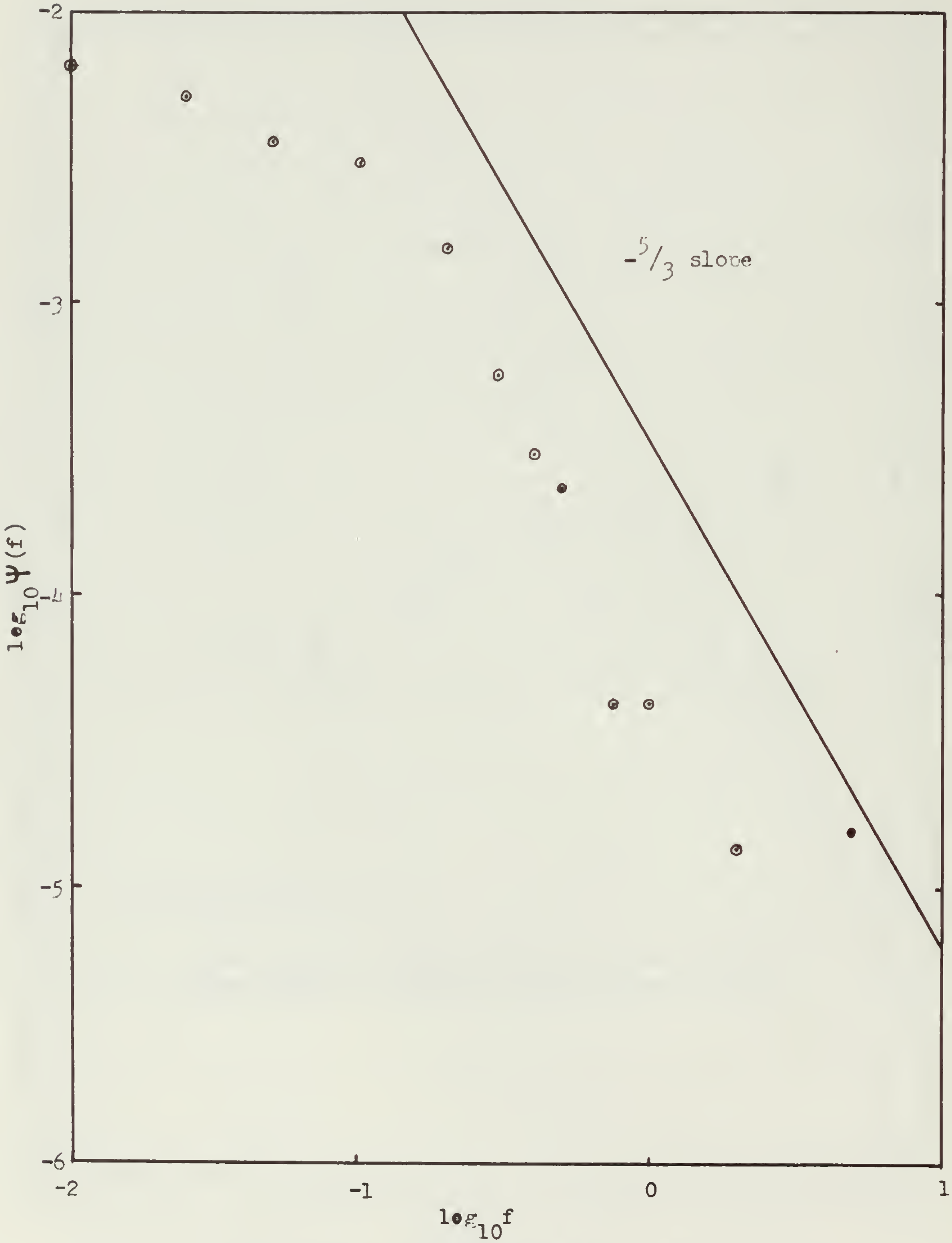


Figure 12. Co-spectrum, Dual-probe Temperatures

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APPENDIX A

Confidence Interval Calculations

Record length = T_r = 120 seconds

Sampling interval = f = 0.1 seconds

No. of lags per record length = m = 200

Degrees of freedom = d

No. of data points = N

$$N = \frac{T_r}{t}$$
$$= \frac{120}{0.1}$$
$$= 1200$$
$$d = \frac{2N}{m} \qquad \text{(Blackman and Tukey, 1958)}$$
$$= \frac{2400}{200}$$
$$= 12$$

The confidence interval is defined

$$\frac{d\sigma^2}{\chi^2_{d;\alpha/2}} \leq \sigma_x^2 \leq \frac{d\sigma^2}{\chi^2_{d;1-\alpha/2}} \qquad \text{(Bendat and Piersol, 1966)}$$

Assuming that the Fourier transform bears the same relation, α = 0.2 and d = 12, gives values for $\chi^2_{d;\alpha/2}$ and $\chi^2_{d;1-\alpha/2}$ of:

$\chi^2_{d;\alpha/2} = 26.22$

$\chi^2_{d;1-\alpha/2} = 6.30$

then: $$\frac{12\,\Psi(f)}{26.22} \leq \Psi(f) \leq \frac{12\,\Psi(f)}{6.30}$$

The interval is then:

$$0.65\,\Psi(f) \leq \Psi(f) \leq 1.91\,\Psi(f)$$

TABLE I

```
C.......................................................................
C
C     PROGRAM BLACKY  (FORTRAN IV FOR OS/360)
C
C     PURPOSE: THIS TIME SERIES ANALYSIS PROGRAM COMPUTES FOR TWO
C              SIMULTANEOUS TIME SERIES (6000 OR LESS MEASUREMENTS EACH)
C              THE CROSS (CO- AND QUADRATURE-) SPECTRA AND THE TWO POWER
C              SPECTRA. PHASE AND COHERENCE ARE CALCULATED FROM THE
C              CROSS SPECTRA AND POWER SPECTRA.
C
C     USAGE: PROGRAM BLACKY IS A MAIN PROGRAM AND HAS TO BE EXECUTED IN
C            THE SAME FASHION AS ALL MAIN PROGRAMS;I.E., IT CANNOT BE
C            CALLED BY ANOTHER PROGRAM SINCE IT IS NOT A SUBROUTINE.
C            THE DATA DECK SET-UP IS AS FOLLOWS:
C            (A) CONTROL CARD WITH FORMAT(10I3)
C                LOP: = ''0'' AND MUST BE ''0'' (CARRY-OVER PARAMETER
C                       FROM THE ORIGINAL PROGRAM)
C                KL: GENERATES A ''1+COS'' SET OF FILTER WEIGHTS KL TIME
C                    STEPS LONG FOR USE AS THE LOW-PASS FILTER. THE
C                    NUMBER OF FILTER WEIGHTS MUST BE .LE. 550.
C                KH: GENERATES A ''1+COS'' SET OF FILTER WEIGHTS KH LONG
C                    FOR USE AS THE HIGH-PASS FILTER. THE NUMBER OF
C                    FILTER WEIGHTS MUST BE .LE. 50.
C                NL: THE NUMBER OF FILTER WEIGHTS TO BE READ IN AS A
C                    LOW-PASS FILTER (KL MUST BE 0 IF NL .NE. 0).
C                    THE NUMBER OF WEIGHTS MUST BE .LT. 550.
C                NH: THE NUMBER OF FILTER WEIGHTS TO BE READ IN AS A
C                    HIGH-PASS FILTER(KH MUST BE 0 IF NH .NE. 0).
C                    THE NUMBER OF WEIGHTS MUST BE .LT. 50.
C                NDCMT: THE NUMBER OF ADVANCES FOR LOW-PASS FILTER. ANY
C                    REASONABLE NUMBER OF ADVANCES MAY BE USED.
C                NTIMES: THE NUMBER OF TIMES LOW-PASS FILTER IS TO BE
C                    APPLIED. ANY REASONABLE NUMBER OF TIMES MAY BE
C                    USED.
C                NDEG: =''0'' REMOVES MEAN OF SERIES,
C                      =''1''  REMOVES TREND
C                LAGS: NUMBER OF SPECTRAL ESTIMATES AND LAGS IN AUTO-
C                    AND CROSS-CORRELATION. LAGS MUST BE .LE. 500.
C                JUBN: =''1''FOR THE LAST DATA DECK,
C                      =''0'' FOR PRECEDING DECKS.
C            (B) LOW-PASS FILTER DECK, FORMAT(7F10.6)
C                IF NL .NE. 0, THIS FILTER DECK MUST BE PRESENT.
C            (C) HIGH-PASS FILTER DECK, FORMAT(7F10.6)
C                IF NH .NE. 0, THIS FILTER DECK MUST BE PRESENT.
C            (D) TITLE CARD 1, FORMAT(2A8,I5,F7.1,6A8)
```

```
C                  THE FOUR ITEMS ON THIS CARD ARE:
C                  (1) FORMAT OF THE TIME SERIES DATA FOLLOWING
C                  (2) THE NUMBER OF ELEMENTS IN THE TIME SERIES
C                      (THIS NUMBER MUST BE .LE. 6000).
C                  (3) TIME INTERVAL, DELTA T, FOR THE TIME SERIES
C                  (4) TITLE OF THE SERIES, USED ONLY FOR IDENTIFICATION
C              (E) TIME SERIES 1, FORMAT AS SPECIFIED IN (D) AND (4) ABOVE
C              (F) TITLE CARD 2, SEE (D) ABOVE
C              (G) TIME SERIES 2, FORMAT AS SPECIFIED IN (F) AND (4) ABOVE
C
C      REMARKS: THIS TIME SERIES ANALYSIS PROGRAM CONTAINS THREE BASIC
C               SUBPROGRAMS. THE FIRST TWO, FILTER AND REMOVAL OF TREND,
C               PREPARE THE DATA(TWO TIME SERIES AT EQUAL TIME INTERVALS)
C               FOR THE SPECTRUM ANALYSIS SUBPROGRAM.
C               (A) SUBROUTINE FILTER PERFORMS A SIMPLE RUNNING WEIGHTED
C                   AVERAGE. THE WEIGHTS W(K) ARE EITHER SUPPLIED BY THE
C                   USER OR IF KH OR KL IS NOT EQUAL TO ZERO, ARE
C                   GENERATED BY THE MAIN PROGRAM  (SEE STATEMENTS 12-14
C                   AND 15-40 IN PROGRAM LISTING).
C                   X(I)=SUMMATION OF B(I+K)*W(K) WHERE K=0,1,...,N-1.
C                   B(I) IS THE ORIGINAL SERIES.
C                   X(I) IS THE FILTERED SERIES.
C                   W(K) IS THE WEIGHTING FUNCTION.
C                   THE FILTERED SERIES IS ALWAYS SHORTER THAN THE
C                   ORIGINAL SERIES BY THE NUMBER OF WEIGHTS N,MINUS ONE.
C                   IF NDCMT .NE. 1, THEN X(I) IS COMPUTED  ONLY FOR
C                   I=1,1+NDCMT,1+2*NDCMT,1+3*NDCMT,...
C               (B) SUBROUTINE DETRND REMOVES THE MEAN FROM A TIME SERIES
C                   AND IF NDEG=1 REMOVES THE ''LEAST SQUARES TREND''
C               (C) SUBROUTINE COQUAD COMPUTES THE AUTO- AND CROSS-
C                   CORRELATIONS AND FROM THESE, THE SPECTRA AND CROSS-
C                   SPECTRA.
C               (D) OUTPUT PRODUCED BY BLACKY ON SYSOUT IS LABELLED AND
C                   SHOULD BE SELF-EXPLANATORY.
C         REFERENCES: FOR DETAILED DISCUSSION OF THE MATHEMATICAL METHOD
C                   SEE ''THE MEASUREMENT OF POWER SPECTRA'' BY BLACKMAN
C                   AND TUKEY, DOVER PUBLICATIONS, 1958. ALSO SEE THE
C                   DOCUMENTATION WITH CO-OP ID: G6 UCSD TUKEY BY
C                   GAYLORD MILLER, AUGUST 11,1961.
C
      REAL*8 IFMT(2),ID(6)
      DIMENSION            A(1000),B(3000),X(3000),Y(3000),F(100)
     1,FHP(500),FLP(550)
      EQUIVALENCE(B,Y)
  500 FORMAT(2A8,I5,F7.1,6A8)
```

```
501 FORMAT(14I3)
502 FORMAT(5I6)
503 FORMAT(7F10.6)
504 FORMAT(29H0COEFF FOR NOMINAL PASS BAND 2I6 )
505 FORMAT(13H0DECIMATE BY I6, 7H RESULT I5, 8H POINTS   )
506 FORMAT(1H0, 40X,I5, 13H POINTS FROM 6A8)
 30 READ(5,501) LOP,KL,KH,NL,NH,NDCMT,NTIMES,NDEG,LAGS,JUBN
    IF(LOP)10,11,10
 10 READ(5,502) M,NA,NAA,NF,ND
    READ(5,503) (F(I),I=1,NF)
 11 IF(NL) 17,18,17
 17 READ(5,503) (FLP(I),I=1,NL)
 18 IF(NH)19,20,19
 19 READ(5,503) (FHP(I),I=1,NH)
 20 PI=3.1415926
    IF(KL) 12,13,12
 12 NL=2*KL-1
    XKL=KL
    DO 14 I=1,NL
    XI=I
 14 FLP(I)=0.5/XKL*(1.0+COS(PI*(XI-XKL)/XKL))
 13 IF(KH)15,44,15
 15 NH=2*KH-1
    XKH=KH
    DO 40 I=1,NH
    XI=I
 40 FHP(I)=-0.5/XKH*(1.0+COS(PI*(XI-XKH)/XKH))
    FHP(KH)=FHP(KH)+1.0
    WRITE(6,504) KL,KH
 44 DO 29 II=1,2
    IF(LOP)43,32,43
 32 READ(5,500) (IFMT(I),I=1,2),N,DT,(ID(I),I=1,6)
    READ(5,IFMT)(B(I),I=1,N)
    GO TO 16
 43 N=NB
 16 IF(NTIMES)23,24,23
 23 DO 21 I=1,NTIMES
    CALL FILTER(B,N,FLP,NL,B,NC)
    N=NC
    JJ=1
    DCMT=NDCMT
    DT=DT*DCMT
    DO 22 J=1,N,NDCMT
    B(JJ)=B(J)
 22 JJ=JJ+1
```

```
      N=JJ-1
   21 WRITE(6,505) NDCMT,N
   24 IF(NH)25,26,25
   25 CALL FILTER(B,N,FHP,NH,B,NC)
      N=NC
   26 GO TO(27,28),II
   27 CALL DETRND(B,N,X,NDEG)
      GO TO 29
   28 CALL DETRND(B,N,Y,NDEG)
   29 WRITE(6,506) N, (ID(I),I=1,6)
      CALL COQUAD(N,LAGS,X,Y,DT)
      IF(JUBN)1301,30,1301
 1301 STOP
      END



      SUBROUTINE FILTER(A,NA,F,NF,B,NB)
      DIMENSION A(1000),B(3000),F(100)
      NB=NA-NF+1
      DO 11 I=1,NB
      SUM=0.0
      DO 10 K=1,NF
      L=I+K-1
   10 SUM=SUM+F(K)*A(L)
   11 B(I)=SUM
      WRITE(6,100) NF,(F(I),I=1,NF)
  100 FORMAT(12H0FILTER WITHI4,12HCOEFFICIENTS//(10F10.4))
      RETURN
      END



      SUBROUTINE DETRND(X,N,Y,NDEG)
      DIMENSION X(3000),Y(3000)
      AN=N
      S1=0.0
      DO 10 I=1,N
   10 S1=S1+X(I)
      AVEX=S1/AN
      DO 11 I=1,N
```

```
 11 Y(I)=X(I)-AVEX
    IF(NDEG)12,12,13
 13 S1=0.0
    S2=0.0
    DO 14 I=1,N
    S1=S1+Y(I)
 14 S2=S2+S1
    AVEI=(AN+1.0)/2.0
    B=-12.0*S2/(AN*(AN**2-1.0))
    DO 15 I=1,N
    AI=I
 15 Y(I)=Y(I)-B*(AI-AVEI)
 12 WRITE(6,200) NDEG
200 FORMAT(23HOREMOVE TREND OF DEGREEI2)
    RETURN
    END



    SUBROUTINE COQUAD (NDATA,LAGS,X,Y,DT)
    DIMENSION X(3000),Y(3000),TERM1( 501),TERM2(501),QX(501),QY(501),
   1SUMXL(501),SUMXU(501),SUMYL(501),SUMYU(501),PRODXX(501),PRODYY
   2(501),PRODXY(501),PRODYX(501),QC(501),QQ(501),UY(501),UX(501),
   3UC(501),UQ(501),WX(501),WY(501),WC(501),WQ(501),CS(1002),
   4SN(1002),RUM(501),DEN(501),AR(501),MFH(21)
    EQUIVALENCE (TERM1,RUM),(TERM2,DEN),(QX,WX),(QY,WY),
   1(CS,PRODXX),(SN,PRODXY),(QC,WC),(SUMXL,UX,AR),(SUMXU,UY),(QQ,WQ),
   2(SUMYL,UC),(SUMYU,UQ)
    ZORCH=1.11111
    WRITE(6,502) NDATA
502 FORMAT(1H0,50X,13HNO. OF DATA =I6)
    WRITE(6,503) LAGS
503 FORMAT(1H0,50X13HNO. OF LAGS =I4////)
    NP=LAGS+1
 51 NU=NDATA-LAGS
    SUMX=0.
    SUMY=0.
    DO 12 J=NP,NU
    SUMX=SUMX+X(J)
 12 SUMY=SUMY+Y(J)
    SUMXL(NP)=SUMX
    SUMXU(NP)=SUMX
    SUMYL(NP)=SUMY
```

```
      SUMYU(NP)=SUMY
      DO 13 J=1,LAGS
      SUMXL(NP)=SUMXL(NP)+X(J)
      SUMYL(NP)=SUMYL(NP)+Y(J)
      JJ=NDATA-J+1
      SUMXU(NP)=SUMXU(NP)+X(JJ)
   13 SUMYU(NP)=SUMYU(NP)+Y(JJ)
      DO 14 J=1,LAGS
      JJ=NP-J
      JJJ=NDATA-JJ+1
      SUMXL(JJ)=SUMXL(JJ+1)+X(JJJ)
      SUMYL(JJ)=SUMYL(JJ+1)+Y(JJJ)
      SUMXU(JJ)=SUMXU(JJ+1)+X(JJ)
   14 SUMYU(JJ)=SUMYU(JJ+1)+Y(JJ)
      DO 15 J=1,NP
      PRODXX(J)=0.
      PRODYY(J)=0.
      PRODXY(J)=0.
      PRODYX(J)=0.
      MN=NDATA-J+1
      JM=J
      DO 15 I=1,MN
      PRODXX(J)=PRODXX(J)+X(I)*X(JM)
      PRODYY(J)=PRODYY(J)+Y(I)*Y(JM)
      PRODXY(J)=PRODXY(J)+X(I)*Y(JM)
      PRODYX(J)=PRODYX(J)+Y(I)*X(JM)
   15 JM = JM+1
      DO 18 I=1,NP
      DENOM=NDATA-I+1
      FDEN=1./DENOM
      TERM1(I)=PRODXY(I)-FDEN*SUMYU(I)*SUMXL(I)
      TERM2(I)=PRODYX(I)-FDEN*SUMXU(I)*SUMYL(I)
      QX(I)=FDEN*(PRODXX(I)-FDEN*SUMXU(I)*SUMXL(I))
   18 QY(I)=FDEN*(PRODYY(I)-FDEN*SUMYU(I)*SUMYL(I))
      DO 17 I=1,NP
      TDEN=2*(NDATA-I+1)
      FTDEN=1./TDEN
      QC(I)=FTDEN*(TERM1(I)+TERM2(I))
      QQ(I)=FTDEN*(TERM1(I)-TERM2(I))
   17 MMP=I-1
    8 FORMAT(1PE15.7,1PE17.7,I8,1P4E20.7)
      FLAGS=LAGS
      QX(NP)=.5*QX(NP)
      QY(NP)=.5*QY(NP)
      QC(NP)=.5*QC(NP)
```

```
      DO 65 I=1,NP
      UX(I)=.5*QX(1)
      UY(I)=.5*QY(1)
   65 UC(I)=.5*QC(1)
      DO 70 I=2,NP
      UX(1)=UX(1)+QX(I)
      UY(1)=UY(1)+QY(I)
      UC(1)=UC(1)+QC(I)
      UX(NP)=-UX(NP)+QX(I)
      UY(NP)=-UY(NP)+QY(I)
   70 UC(NP)=-UC(NP)+QC(I)
      IF(LAGS-2*(LAGS/2)) 700,701,702
  700 RETURN
  701 EX=1.
      GO TO 703
  702 EX=-1.
  703 UX(NP)=EX*UX(NP)
      UY(NP)=EX*UY(NP)
      UC(NP)=EX*UC(NP)
      UQ(1)=0.
      UQ(NP)=UQ(1)
      QQ(NP)=.5*QQ(NP)
      DO 80 I=2,LAGS
   80 UQ(I)=.5*QQ(1)
      PI=3.141592654
      LAGTWO=LAGS+LAGS
      ANG=PI/FLAGS
      DO 157 I=1,LAGTWO
      FI=I-1
      G=FI*ANG
      CS(I)=COS(G)
  157 SN(I)=SIN(G)
      DO 90 I=2,LAGS
      DO 90 J=2,NP
  158 JREM=(I-1)*(J-1)
      JJ= MOD (JREM,LAGTWO)+1
      UX(I)=UX(I)+CS(JJ)*QX(J)
      UY(I)=UY(I)+CS(JJ)*QY(J)
      UC(I)=UC(I)+CS(JJ)*QC(J)
   90 UQ(I)=UQ(I)+SN(JJ)*QQ(J)
      WRITE(6,1234)
 1234 FORMAT(1H110X43HAUTO-CORRELATION AND CROSS-CORRELATION DATA/1H010X
     15HINDEX6X6HAUTO X10X6HAUTO Y9X10HEVEN CROSS5X9HODD CROSS7X8HCROSS
     2YX8X8HCROSS XY)
      WRITE(6,1235)(I,QX(I),QY(I),QC(I),QQ(I),TERM1(I),TERM2(I),
```

```
     1I=1,NP)
1235 FORMAT(I14,6E16.5)
     FLT=2./FLAGS
     DO 95 I=1,NP
     UX(I)=FLT*UX(I)
     UY(I)=FLT*UY(I)
     UC(I)=FLT*UC(I)
     UQ(I)=FLT*UQ(I)
  95 MMP=I-1
  11 FORMAT(I19,1P4E20.7)
     WRITE(6,32)
  32 FORMAT(1H1,44X,30HTHE SMOOTHED SPECTRAL ESTIMATE/1H0)
     WRITE(6,23)
  23 FORMAT(1H03X1HT8X10HSPECTRUM 15X10HSPECTRUM 24X11HCO-SPECTRUM3X
    112HQUA-SPECTRUM5X5HPHASE3X12HCOHERENCE**22X7HLOG(S1)2X7HLOG(S2)3X
    21HK/1H0)
     WX(1)=.5*(UX(1)+UX(2))
     WY(1)=.5*(UY(1)+UY(2))
     WC(1)=.5*(UC(1)+UC(2))
     WQ(1)=.5*UQ(1)
     WX(NP)=.5*(UX(LAGS)+UX(NP))
     WY(NP)=.5*(UY(LAGS)+UY(NP))
     WC(NP)=.5*(UC(LAGS)+UC(NP))
     WQ(NP)=.5*UQ(NP)
     DO 98 I=2,LAGS
     WX(I)=.25*(UX(I-1)+UX(I+1))+.5*UX(I)
     WY(I)=.25*(UY(I-1)+UY(I+1))+.5*UY(I)
     WC(I)=.25*(UC(I-1)+UC(I+1))+.5*UC(I)
  98 WQ(I)=.25*(UQ(I-1)+UQ(I+1))+.5*UQ(I)
     DO 99 I=1,NP
     MMP=I-1
     RUM(I)=SQRT(WC(I)*WC(I)+WQ(I)*WQ(I))
     IF(WC(I)) 42,43,43
  43 IF(WQ(I)) 44,45,45
  42 ADDN=0.5
     GO TO 40
  44 ADDN =1.0
     GO TO 40
  45 ADDN=0.0
  40 ARG=ATAN(WQ(I)/WC(I))/6.283185 +ADDN
     IF(ARG-.5)666,666,667
 667 ARG=ARG-1.
 666 ARG=ARG*360.
     T=WX(I)*WY(I)
     IF(T)101,105,105
```

```
101 DEN(I)=-SQRT(-T)
    GO TO 999
105 DEN(I)=SQRT(T)
    RUM(I)=(RUM(I)/DEN(I) )**2
    SLOG=20.+(ALOG(ABS(WX(I)))/2.3025851)
    SSLOG=20.+(ALOG(ABS(WY(I)))/2.3025851)
    IF(MMP)200,201,200
201 TTT=0.0
    GO TO 999
200 FMMP=MMP
    TTT=2.0*FLAGS*DT / FMMP
    ARG=-ARG
999 WRITE(6,22) TTT,WX(I),WY(I),WC(I),WQ(I),ARG,RUM(I),
   1 SLOG,SSLOG,MMP
 99 CONTINUE
 22 FORMAT(F8.2,1P4E15.4,0PF10.1,F13.3,F11.3,F9.3,I4)
    RETURN
    END
```

TABLE II

Single-Probe Analysis

Period	Spect. Est. - Wave Ampl.	Spect. Est. - Temp.	Co-spectrum	Coherence Square
0.0	9.4362E-01	7.7247E-01	3.5102E-01	0.169
40.00	6.7725E-01	6.2795E-01	3.2119E-01	0.266
20.00	3.0875E-01	3.5411E-01	2.2467E-01	0.531
13.33	1.5026E-01	1.8257E-01	1.0824E-01	0.461
10.00	8.3425E-02	1.0066E-01	5.5300E-02	0.374
8.00	6.7956E-02	5.4316E-02	4.6757E-02	0.597
6.67	6.4900E-02	3.7558E-02	3.3697E-02	0.490
5.71	5.5195E-02	2.2311E-02	2.0760E-02	0.363
5.00	5.0849E-02	1.9620E-02	2.3267E-02	0.600
4.44	6.7168E-02	2.8978E-02	4.0709E-02	0.895
4.00	6.6955E-02	2.8764E-02	3.9573E-02	0.830
3.64	7.3837E-02	1.8866E-02	2.8583E-02	0.658
3.33	7.5058E-02	1.3911E-02	2.4239E-02	0.704
3.08	5.3077E-02	9.8771E-03	1.7650E-02	0.744
2.86	4.4908E-02	7.4048E-03	1.5246E-02	0.815
2.67	3.0051E-02	5.9809E-03	1.0958E-02	0.670
2.50	1.6539E-02	5.5221E-03	6.9742E-03	0.602
2.35	1.5073E-02	5.0688E-03	6.4448E-03	0.545
2.22	9.5668E-03	4.4032E-03	4.3203E-03	0.639
2.11	8.8860E-03	5.3013E-03	4.5994E-03	0.594
2.00	1.7366E-02	5.8005E-03	7.0948E-03	0.597
1.90	1.9625E-02	4.8507E-03	5.9836E-03	0.481
1.82	1.4269E-02	4.6446E-03	4.2901E-03	0.312
1.74	1.0581E-02	3.9100E-03	3.8893E-03	0.397
1.67	9.5497E-03	2.1120E-03	3.2269E-03	0.555
1.60	9.3445E-03	1.7762E-03	2.9128E-03	0.526
1.54	6.2651E-03	1.5574E-03	1.5661E-03	0.366
1.48	3.7958E-03	9.3367E-04	3.7003E-04	0.170
1.43	5.8835E-03	1.0826E-03	5.3606E-04	0.047
1.38	9.5827E-03	1.3018E-03	1.1758E-03	0.111
1.33	9.5795E-03	9.7672E-04	1.2449E-03	0.184
1.29	6.7616E-03	7.4404E-04	1.1885E-03	0.326
1.25	6.2162E-03	4.9718E-04	9.7066E-04	0.325
1.21	5.5827E-03	2.3216E-04	3.5866E-04	0.100
1.18	4.0358E-03	4.8839E-04	4.3499E-04	0.132
1.14	4.6452E-03	6.2668E-04	6.1709E-04	0.279

1.11	5.2303E-03	3.8723E-04	-5.7518E-05	0.072
1.08	5.0714E-03	6.3380E-04	-3.2201E-04	0.117
1.05	6.4956E-03	8.9338E-04	2.1519E-04	0.218
1.03	8.1459E-03	6.8382E-04	4.0173E-04	0.146
1.00	6.4742E-03	7.1180E-04	5.1049E-04	0.057
0.98	4.2218E-03	8.9321E-04	7.0466E-04	0.132
0.95	5.2007E-03	8.7656E-04	2.2763E-05	0.160
0.93	7.7650E-03	7.1323E-04	-5.0271E-04	0.237
0.91	9.8724E-03	4.4446E-04	-1.5825E-05	0.117
0.89	8.0866E-03	2.2772E-04	2.1490E-04	0.362
0.87	2.7373E-02	2.7563E-04	-1.5378E-03	0.426
0.85	8.6543E-02	5.1205E-04	-4.1847E-03	0.499
0.83	1.3360E-01	6.6298E-04	-2.5360E-03	0.325
0.82	1.1080E-01	5.5958E-04	7.7151E-04	0.293
0.80	4.9880E-02	6.2068E-04	-3.5255E-04	0.078
0.78	1.8900E-02	7.2306E-04	-1.4135E-03	0.238
0.77	1.3458E-02	5.0236E-04	2.3547E-04	0.220
0.75	1.3042E-02	4.7103E-04	8.5794E-04	0.153
0.74	2.0564E-02	5.0542E-04	7.7074E-04	0.073
0.73	2.0636E-02	3.5844E-04	8.1388E-04	0.104
0.71	1.4428E-02	3.5485E-04	2.0806E-04	0.038
0.70	1.9467E-02	3.9675E-04	-2.4140E-04	0.035
0.69	2.9320E-02	3.4590E-04	-6.3381E-04	0.099
0.68	3.5950E-02	3.7611E-04	-4.0132E-04	0.269
0.67	2.8623E-02	3.4691E-04	7.1387E-04	0.312
0.66	1.4802E-02	1.9337E-04	5.0101E-04	0.193
0.65	1.5118E-02	2.1986E-04	-7.5513E-04	0.389
0.63	1.7966E-02	3.5814E-04	-8.2750E-04	0.388
0.62	1.8433E-02	3.4829E-04	2.7871E-04	0.375
0.62	1.8373E-02	2.2199E-04	7.5955E-04	0.417
0.61	1.3868E-02	1.6346E-04	3.5355E-04	0.156
0.60	8.0924E-03	1.7179E-04	2.6173E-04	0.218
0.59	4.5702E-03	1.6011E-04	4.3329E-04	0.328
0.58	5.4949E-03	1.5930E-04	3.2220E-04	0.119
0.57	7.6967E-03	1.3132E-04	-1.3916E-05	0.021
0.56	8.4779E-03	8.9688E-05	-9.7933E-05	0.084
0.56	7.7439E-03	1.3871E-04	4.1786E-04	0.202
0.55	5.6913E-03	1.8708E-04	6.8485E-04	0.479
0.54	3.7031E-03	1.3094E-04	3.1442E-04	0.340
0.53	4.6633E-03	1.0036E-04	3.2078E-04	0.355
0.53	8.5682E-03	1.4738E-04	5.8145E-04	0.268
0.52	8.1773E-03	1.4356E-04	3.3218E-04	0.099
0.51	4.2917E-03	7.7236E-05	2.0344E-05	0.018
0.51	2.4703E-03	7.7920E-05	7.6358E-05	0.136
0.50	1.9684E-03	1.2740E-04	1.2428E-04	0.506
0.49	2.0608E-03	1.4076E-04	1.3937E-04	0.564
0.49	2.9554E-03	1.4642E-04	2.9283E-04	0.326
0.48	4.3850E-03	1.0408E-04	3.0937E-04	0.271

0.48	3.8783E-03	6.7038E-05	2.0616E-04	0.223
0.47	1.6610E-03	1.2748E-04	1.5187E-04	0.143
0.47	1.5550E-03	1.3195E-04	1.4555E-04	0.151
0.46	2.3269E-03	6.0694E-05	9.0173E-05	0.208
0.45	2.2626E-03	4.5485E-05	4.0616E-05	0.045
0.45	2.5263E-03	1.0779E-04	1.4725E-04	0.093
0.44	2.3136E-03	1.8528E-04	2.0958E-04	0.118
0.44	1.6685E-03	1.6668E-04	1.2076E-04	0.090
0.43	1.4769E-03	9.5542E-05	5.4907E-05	0.094
0.43	1.8642E-03	5.7002E-05	2.4890E-05	0.037
0.43	2.3620E-03	5.9974E-05	-1.9241E-05	0.003
0.42	1.9955E-03	6.6974E-05	3.9174E-08	0.025
0.42	1.6464E-03	5.4221E-05	-2.5029E-05	0.023
0.41	2.0256E-03	7.6271E-05	1.5566E-05	0.179
0.41	1.8752E-03	6.9090E-05	1.0182E-04	0.226
0.40	1.0010E-03	2.1953E-05	2.3382E-05	0.028
0.40	5.7728E-04	1.2626E-05	-1.5584E-05	0.034
0.40	6.3425E-04	1.4052E-05	1.4635E-05	0.033
0.39	6.5533E-04	1.2366E-05	1.4804E-05	0.078
0.39	4.3815E-04	2.4202E-05	1.0076E-05	0.027
0.38	5.3650E-04	4.6068E-05	4.5166E-05	0.085
0.38	1.0982E-03	4.0633E-05	7.7194E-05	0.134
0.38	1.2347E-03	1.8787E-05	1.7539E-05	0.027
0.37	1.0658E-03	4.2324E-05	3.2052E-05	0.050
0.37	9.2771E-04	7.4915E-05	1.2693E-04	0.487
0.37	6.2849E-04	7.0912E-05	1.0805E-04	0.610
0.36	4.4502E-04	7.3111E-05	8.3155E-05	0.418
0.36	6.6693E-04	7.5645E-05	1.1272E-04	0.327
0.36	8.6860E-04	6.5171E-05	5.3201E-05	0.111
0.35	7.9832E-04	7.6864E-05	-5.8159E-05	0.120
0.35	5.5627E-04	8.6796E-05	-5.1442E-05	0.055
0.35	2.5449E-04	6.3873E-05	1.8077E-05	0.133
0.34	1.7378E-04	4.3292E-05	2.0113E-05	0.201
0.34	2.1044E-04	4.3294E-05	9.6469E-06	0.142
0.34	2.3280E-04	4.0828E-05	-4.5172E-06	0.005
0.34	3.6100E-04	4.9709E-05	-2.1537E-05	0.179
0.33	4.6544E-04	5.5237E-05	-7.3809E-06	0.094
0.33	2.9261E-04	3.0841E-05	-6.4427E-06	0.013
0.33	1.4974E-04	1.8703E-05	6.4789E-06	0.131
0.33	2.9615E-04	2.4367E-05	3.6243E-05	0.225
0.32	3.4702E-04	3.1493E-05	2.4218E-05	0.103
0.32	2.7979E-04	3.8551E-05	-9.1581E-06	0.040
0.32	3.1679E-04	3.4374E-05	-1.1926E-05	0.082
0.31	3.2697E-04	2.8926E-05	1.5824E-05	0.055
0.31	2.2459E-04	2.4473E-05	1.7936E-05	0.267
0.31	1.7714E-04	2.5657E-05	-1.0308E-05	0.027
0.31	2.6798E-04	4.4795E-05	4.7173E-06	0.210
0.31	4.3030E-04	5.1061E-05	4.7010E-05	0.147

0.30	4.7358E-04	3.6322E-05	4.2944E-05	0.108
0.30	2.9390E-04	2.6070E-05	1.2483E-05	0.031
0.30	1.3820E-04	2.0587E-05	-3.9093E-06	0.084
0.30	1.0260E-04	2.5495E-05	5.2300E-07	0.020
0.29	1.3666E-04	3.3768E-05	-8.3170E-06	0.029
0.29	2.0982E-04	2.5443E-05	-3.1156E-05	0.194
0.29	2.7276E-04	1.9536E-05	-2.7571E-05	0.184
0.29	2.8386E-04	2.3565E-05	-1.6276E-05	0.167
0.29	2.9853E-04	1.7762E-05	-7.1125E-06	0.195
0.28	3.0872E-04	1.2954E-05	-4.8239E-06	0.173
0.28	1.7309E-04	1.8539E-05	-2.8363E-06	0.118
0.28	1.3111E-04	3.3266E-05	2.4074E-06	0.003
0.28	2.0823E-04	4.6997E-05	-1.2049E-05	0.020
0.28	1.6066E-04	4.0982E-05	-2.2036E-05	0.099
0.27	1.4185E-04	3.1483E-05	-1.1952E-05	0.076
0.27	1.7860E-04	3.0571E-05	-3.8321E-06	0.006
0.27	1.5089E-04	2.4713E-05	-1.9673E-05	0.105
0.27	1.5890E-04	1.9763E-05	-1.1974E-05	0.096
0.27	1.6870E-04	2.6155E-05	2.5735E-05	0.209
0.26	1.5711E-04	2.5573E-05	1.4827E-05	0.068
0.26	2.2137E-04	2.2961E-05	-1.3074E-05	0.049
0.26	2.7174E-04	3.8517E-05	3.1102E-06	0.018
0.26	1.8993E-04	5.0748E-05	1.9703E-05	0.096
0.26	1.3123E-04	4.5291E-05	7.0681E-06	0.037
0.26	2.0951E-04	4.1902E-05	1.0689E-05	0.036
0.25	2.1288E-04	4.3426E-05	2.4460E-05	0.073
0.25	1.5561E-04	4.3285E-05	1.9598E-05	0.069
0.25	1.9033E-04	4.5614E-05	1.8510E-05	0.080
0.25	2.2502E-04	4.4425E-05	8.7840E-06	0.111
0.25	1.4776E-04	3.6933E-05	-9.6103E-06	0.228
0.25	8.5453E-05	2.7844E-05	-7.5939E-06	0.073
0.25	1.3114E-04	1.9281E-05	7.9717E-07	0.011
0.24	1.4016E-04	1.9645E-05	-9.2028E-07	0.005
0.24	1.1173E-04	2.7669E-05	-7.0268E-06	0.022
0.24	1.0828E-04	2.6878E-05	-7.5851E-06	0.041
0.24	1.5609E-04	2.3963E-05	8.4792E-06	0.073
0.24	1.8847E-04	2.6489E-05	2.4628E-05	0.168
0.24	1.3791E-04	2.9056E-05	8.7427E-06	0.077
0.24	9.1462E-05	3.0867E-05	-8.4248E-06	0.048
0.23	7.8830E-05	3.0933E-05	-6.1308E-06	0.022
0.23	1.0615E-04	3.3068E-05	-8.3090E-06	0.032
0.23	1.2945E-04	3.5633E-05	-1.5739E-05	0.083
0.23	1.1616E-04	3.2720E-05	-1.9044E-05	0.118
0.23	1.0072E-04	2.7396E-05	-1.4492E-05	0.214
0.23	8.9998E-05	2.3467E-05	-1.0816E-05	0.325
0.23	8.9230E-05	1.9040E-05	3.0907E-06	0.228
0.22	9.4811E-05	1.8802E-05	8.9488E-06	0.045
0.22	1.1080E-04	2.5556E-05	-3.8795E-06	0.015

0.22	1.1527E-04	3.2530E-05	8.4499E-06	0.032
0.22	9.2006E-05	3.7206E-05	2.7556E-05	0.344
0.22	1.1140E-04	4.1037E-05	2.4725E-05	0.260
0.22	1.3986E-04	3.6557E-05	1.2260E-05	0.123
0.22	1.0003E-04	3.1532E-05	1.6126E-05	0.128
0.22	4.8746E-05	3.1794E-05	2.5937E-05	0.435
0.22	2.3833E-05	2.7235E-05	9.2224E-06	0.134
0.21	4.9652E-05	2.5701E-05	-1.0324E-05	0.119
0.21	1.0535E-04	2.5197E-05	-4.5089E-06	0.096
0.21	1.3481E-04	2.0906E-05	6.4956E-06	0.015
0.21	1.5988E-04	1.6897E-05	3.9723E-06	0.220
0.21	1.5370E-04	1.3747E-05	2.5876E-06	0.241
0.21	9.6784E-05	1.2642E-05	8.8232E-06	0.076
0.21	5.6968E-05	1.5431E-05	1.1998E-05	0.261
0.21	4.0858E-05	2.2777E-05	7.2024E-06	0.065
0.21	5.3553E-05	2.9130E-05	7.6637E-07	0.009
0.20	8.7541E-05	3.1091E-05	-3.1202E-06	0.005
0.20	8.9865E-05	3.6301E-05	-1.1107E-05	0.041
0.20	7.7904E-05	4.5303E-05	-2.2265E-05	0.162
0.20	6.2638E-05	4.6869E-05	-1.5467E-05	0.189
0.20	4.9907E-05	4.4753E-05	-4.1606E-06	0.008

TABLE III

Dual-probe Analysis

Period	Spect. Est. - Temp. 2.5 cm	Spect. Est. - Temp. 5 cm	Co-spectrum	Coherence Square	Spect. Est. - Wave Ampl.
0.0	5.9025E-02	7.4317E-02	6.5187E-02	0.969	3.1100E-03
40.00	4.6143E-02	5.6968E-02	5.0232E-02	0.960	2.4337E-03
20.00	3.1091E-02	4.2747E-02	3.5511E-02	0.951	1.9500E-03
13.33	3.0039E-02	4.7136E-02	3.6777E-02	0.960	2.4322E-03
10.00	2.6289E-02	3.8951E-02	3.0735E-02	0.949	2.1910E-03
8.00	1.6656E-02	2.2662E-02	1.8185E-02	0.952	1.9733E-03
6.67	1.1809E-02	1.6143E-02	1.2656E-02	0.899	2.5350E-03
5.71	1.1500E-02	1.7906E-02	1.3033E-02	0.879	2.5129E-03
5.00	8.1718E-03	1.5209E-02	1.0162E-02	0.905	1.7974E-03
4.44	5.2145E-03	9.3052E-03	6.0145E-03	0.864	1.4037E-03
4.00	7.1401E-03	9.6553E-03	6.8889E-03	0.877	2.0523E-03
3.64	8.0008E-03	1.1754E-02	8.3700E-03	0.902	2.1141E-03
3.33	4.5307E-03	8.9621E-03	5.5988E-03	0.859	1.3306E-03
3.08	1.4985E-03	5.6005E-03	2.5074E-03	0.783	1.5167E-03
2.86	1.1605E-03	4.4262E-03	1.8915E-03	0.739	1.9553E-03
2.67	1.8487E-03	3.7879E-03	2.0854E-03	0.703	1.5637E-03
2.50	2.9439E-03	4.6514E-03	3.0664E-03	0.783	1.1738E-03
2.35	3.4218E-03	5.8906E-03	3.9387E-03	0.839	1.5227E-03
2.22	2.9836E-03	5.5889E-03	3.6767E-03	0.856	1.4688E-03
2.11	2.1503E-03	4.4300E-03	2.7440E-03	0.871	9.1644E-04
2.00	1.7383E-03	4.3040E-03	2.2836E-03	0.885	1.0083E-03
1.90	2.5720E-03	5.7890E-03	3.3667E-03	0.888	1.1222E-03
1.82	2.9700E-03	6.1966E-03	3.9427E-03	0.917	8.0957E-04
1.74	1.7178E-03	3.5515E-03	2.2369E-03	0.876	5.2909E-04
1.67	7.5083E-04	1.3297E-03	8.8514E-04	0.826	3.8342E-04
1.60	9.7654E-04	1.5474E-03	1.1564E-03	0.918	5.4407E-04
1.54	1.5714E-03	2.2755E-03	1.7680E-03	0.911	8.1653E-04
1.48	1.6755E-03	2.5033E-03	1.9291E-03	0.910	8.1722E-04
1.43	1.1464E-03	2.0475E-03	1.4464E-03	0.902	7.0424E-04
1.38	6.7962E-04	1.3997E-03	7.9803E-04	0.687	5.0215E-04
1.33	5.5104E-04	1.0007E-03	4.2337E-04	0.337	3.1525E-04
1.29	5.5976E-04	7.9777E-04	4.3364E-04	0.427	3.8740E-04
1.25	6.1142E-04	7.1959E-04	5.7030E-04	0.759	5.7307E-04
1.21	7.6652E-04	7.4612E-04	6.8186E-04	0.835	5.0760E-04
1.18	8.7825E-04	8.2110E-04	7.8219E-04	0.858	5.8769E-04
1.14	6.6114E-04	6.7750E-04	6.0211E-04	0.810	8.7525E-04

1.11	3.8261E-04	5.4245E-04	3.7680E-04	0.688	6.6449E-04
1.08	3.1738E-04	6.2110E-04	3.5508E-04	0.669	4.3646E-04
1.05	4.1599E-04	7.4025E-04	4.4189E-04	0.709	3.3247E-04
1.03	4.2351E-04	7.0445E-04	4.4834E-04	0.690	3.3390E-04
1.00	3.5214E-04	6.9051E-04	4.2504E-04	0.751	7.6763E-04
0.98	3.5609E-04	7.1401E-04	4.3046E-04	0.736	8.8080E-04
0.95	2.9806E-04	5.9653E-04	3.5808E-04	0.722	6.9519E-04
0.93	2.2677E-04	4.4582E-04	2.6219E-04	0.695	1.2212E-03
0.91	2.0812E-04	2.8730E-04	1.7279E-04	0.526	2.1198E-03
0.89	1.6680E-04	3.1139E-04	1.6364E-04	0.527	2.8041E-03
0.87	1.2729E-04	4.0822E-04	1.8487E-04	0.658	4.8096E-03
0.85	1.8949E-04	4.4248E-04	2.4866E-04	0.741	4.8717E-03
0.83	2.5029E-04	5.2118E-04	3.2545E-04	0.813	5.8738E-03
0.82	1.9932E-04	5.2310E-04	2.7157E-04	0.730	1.1814E-02
0.80	1.5153E-04	4.4190E-04	1.9297E-04	0.597	1.1935E-02
0.78	2.0268E-04	5.4679E-04	2.6610E-04	0.672	1.1559E-02
0.77	2.7759E-04	7.7834E-04	4.0588E-04	0.771	1.3727E-02
0.75	3.1879E-04	7.2473E-04	4.1807E-04	0.762	1.1475E-02
0.74	3.8409E-04	6.6888E-04	4.4310E-04	0.775	1.4261E-02
0.73	3.4190E-04	6.8137E-04	4.2776E-04	0.796	1.7354E-02
0.71	2.0761E-04	4.3421E-04	2.4892E-04	0.706	1.1088E-02
0.70	1.6263E-04	2.8391E-04	1.7140E-04	0.641	6.0609E-03
0.69	1.2791E-04	2.8743E-04	1.5185E-04	0.627	7.3071E-03
0.68	1.1028E-04	2.8996E-04	1.2940E-04	0.570	6.7850E-03
0.67	1.8030E-04	3.2896E-04	1.9925E-04	0.726	4.4122E-03
0.66	2.2944E-04	2.9531E-04	2.2612E-04	0.778	4.6670E-03
0.65	2.3045E-04	3.6235E-04	2.5099E-04	0.756	5.2317E-03
0.63	1.8571E-04	4.3540E-04	2.5099E-04	0.780	4.7719E-03
0.62	1.1507E-04	2.5527E-04	1.3333E-04	0.607	4.3732E-03
0.62	1.6321E-04	1.7345E-04	1.2928E-04	0.649	3.4735E-03
0.61	2.4333E-04	2.1461E-04	1.9807E-04	0.754	2.6523E-03
0.60	2.3152E-04	1.5387E-04	1.6553E-04	0.789	2.3980E-03
0.59	1.7078E-04	1.1197E-04	1.1422E-04	0.730	2.1881E-03
0.58	9.1907E-05	1.0602E-04	7.0158E-05	0.626	1.8499E-03
0.57	6.8934E-05	8.1933E-05	4.1396E-05	0.321	1.7102E-03
0.56	1.0431E-04	9.1756E-05	7.0808E-05	0.583	2.1686E-03
0.56	1.4350E-04	1.0250E-04	1.0245E-04	0.726	1.8704E-03
0.55	1.4270E-04	7.0557E-05	8.4296E-05	0.707	1.0246E-03
0.54	1.4147E-04	1.1976E-04	1.0665E-04	0.703	7.7827E-04
0.53	1.9503E-04	2.0900E-04	1.7783E-04	0.798	8.5921E-04
0.53	1.7547E-04	1.7291E-04	1.5201E-04	0.762	9.2601E-04
0.52	9.9378E-05	1.4880E-04	9.4958E-05	0.611	7.1732E-04
0.51	9.9025E-05	2.0721E-04	1.2045E-04	0.707	4.5166E-04
0.51	1.1718E-04	2.1147E-04	1.3830E-04	0.779	4.9633E-04
0.50	1.1533E-04	1.9872E-04	1.3381E-04	0.782	6.8145E-04
0.49	1.3057E-04	2.0069E-04	1.4657E-04	0.820	4.6220E-04
0.49	1.3957E-04	1.6123E-04	1.2960E-04	0.750	2.1673E-04
0.48	1.2422E-04	1.2509E-04	1.0328E-04	0.695	3.4504E-04
0.48	9.9988E-05	1.0481E-04	8.6803E-05	0.719	5.0782E-04

0.47	7.0708E-05	8.6728E-05	6.1604E-05	0.628	5.2507E-04
0.47	4.5190E-05	7.9565E-05	4.4390E-05	0.629	3.2059E-04
0.46	4.5479E-05	6.3937E-05	3.5473E-05	0.620	1.7852E-04
0.45	6.3345E-05	5.3484E-05	3.5813E-05	0.563	3.0360E-04
0.45	6.9860E-05	5.2508E-05	3.6846E-05	0.423	4.1006E-04
0.44	7.2396E-05	6.0876E-05	4.3478E-05	0.437	3.7973E-04
0.44	6.2593E-05	5.5020E-05	3.9296E-05	0.450	2.6780E-04
0.43	3.8975E-05	3.5877E-05	1.8292E-05	0.240	1.7427E-04
0.43	3.8654E-05	3.3614E-05	1.8318E-05	0.278	1.8130E-04
0.43	5.8269E-05	4.9371E-05	3.6649E-05	0.511	2.0397E-04
0.42	6.2788E-05	6.9243E-05	4.7319E-05	0.520	1.6754E-04
0.42	4.4123E-05	5.8775E-05	3.5888E-05	0.503	1.4289E-04
0.41	2.6987E-05	3.7656E-05	1.5847E-05	0.430	1.5048E-04
0.41	2.0980E-05	3.9143E-05	9.5714E-06	0.408	1.5007E-04
0.40	2.6466E-05	5.3805E-05	2.0155E-05	0.298	1.7820E-04
0.40	4.8639E-05	6.6388E-05	3.5743E-05	0.396	1.7157E-04
0.40	5.4889E-05	6.7072E-05	3.9646E-05	0.446	1.6009E-04
0.39	5.2210E-05	7.4373E-05	4.7431E-05	0.613	1.5429E-04
0.39	5.4933E-05	7.6529E-05	5.3148E-05	0.596	1.4252E-04
0.38	4.6534E-05	7.6466E-05	4.8559E-05	0.664	1.4749E-04
0.38	4.8633E-05	8.2770E-05	5.4030E-05	0.771	9.1939E-05
0.38	4.5037E-05	6.4390E-05	4.4699E-05	0.694	7.5191E-05
0.37	5.2603E-05	7.9961E-05	5.4750E-05	0.752	1.2179E-04
0.37	7.1262E-05	1.0398E-04	7.5545E-05	0.849	1.1030E-04
0.37	4.6985E-05	7.0954E-05	4.3795E-05	0.680	7.4426E-05
0.36	2.5322E-05	4.9093E-05	2.1554E-05	0.390	5.8215E-05
0.36	2.9641E-05	5.2705E-05	3.0906E-05	0.637	5.0600E-05
0.36	2.3406E-05	5.6439E-05	2.7052E-05	0.632	7.4458E-05
0.35	1.6208E-05	5.2105E-05	1.6027E-05	0.305	9.8746E-05
0.35	1.8596E-05	3.3158E-05	1.1730E-05	0.245	9.3396E-05
0.35	3.0027E-05	2.1747E-05	1.5699E-05	0.390	9.3019E-05
0.34	4.0478E-05	2.3618E-05	2.0695E-05	0.562	7.5765E-05
0.34	4.0465E-05	2.3477E-05	2.3322E-05	0.640	3.5453E-05
0.34	3.8526E-05	2.4969E-05	2.2891E-05	0.548	1.9586E-05
0.34	2.9145E-05	4.8303E-05	1.9158E-05	0.283	3.5459E-05
0.33	2.6020E-05	6.9128E-05	2.5955E-05	0.391	5.5368E-05
0.33	3.0470E-05	5.0228E-05	2.9145E-05	0.555	5.9774E-05
0.33	2.2676E-05	2.7465E-05	1.5385E-05	0.433	4.7441E-05
0.33	1.8015E-05	2.4612E-05	7.4302E-06	0.390	3.9975E-05
0.32	2.9385E-05	3.6082E-05	2.1093E-05	0.540	3.4202E-05
0.32	3.0962E-05	4.3717E-05	2.8666E-05	0.674	3.0206E-05
0.32	2.2305E-05	3.2167E-05	2.0006E-05	0.563	4.3858E-05
0.31	3.0516E-05	2.5707E-05	1.8082E-05	0.458	4.1773E-05
0.31	3.9879E-05	2.7748E-05	1.7800E-05	0.538	1.9907E-05
0.31	2.6587E-05	3.2522E-05	1.2286E-05	0.304	1.2976E-05
0.31	1.2381E-05	3.5761E-05	1.1521E-05	0.300	2.0189E-05
0.31	1.7688E-05	3.4255E-05	2.0054E-05	0.666	2.8079E-05

0.30	2.4017E-05	3.4401E-05	2.4523E-05	0.731	3.4041E-05
0.30	2.4313E-05	2.9630E-05	1.9275E-05	0.528	3.9514E-05
0.30	2.3342E-05	2.0838E-05	1.1719E-05	0.283	4.1776E-05
0.30	1.6224E-05	1.5596E-05	5.8552E-06	0.136	3.6604E-05
0.29	1.4443E-05	2.1121E-05	8.3121E-06	0.289	3.1658E-05
0.29	2.1186E-05	3.2956E-05	1.5899E-05	0.441	2.3946E-05
0.29	2.6115E-05	3.0716E-05	1.7244E-05	0.406	1.7027E-05
0.29	2.5177E-05	2.1712E-05	1.2613E-05	0.322	2.1798E-05
0.29	1.7715E-05	2.1924E-05	1.0399E-05	0.318	2.7228E-05
0.28	2.0161E-05	2.4849E-05	1.5921E-05	0.612	2.8357E-05
0.28	2.4484E-05	2.4337E-05	1.7734E-05	0.708	2.5214E-05
0.28	2.0075E-05	2.4916E-05	1.2816E-05	0.448	2.0075E-05
0.28	1.6305E-05	2.4743E-05	1.0934E-05	0.393	2.3005E-05
0.28	1.3786E-05	2.7111E-05	1.1320E-05	0.538	3.6261E-05
0.27	1.4931E-05	3.8812E-05	1.2071E-05	0.589	4.1613E-05
0.27	2.2295E-05	3.8838E-05	1.5497E-05	0.517	3.3194E-05
0.27	3.1206E-05	2.9692E-05	2.0073E-05	0.622	2.4966E-05
0.27	2.3552E-05	2.4276E-05	1.5168E-05	0.613	1.6997E-05
0.27	1.1460E-05	1.6973E-05	7.3368E-06	0.405	2.3296E-05
0.26	1.1602E-05	1.8694E-05	7.0886E-06	0.371	3.8489E-05
0.26	1.1485E-05	2.3174E-05	5.6445E-06	0.228	3.3079E-05
0.26	8.5841E-06	2.4352E-05	4.9662E-06	0.161	2.3802E-05
0.26	6.4268E-06	2.5561E-05	6.4885E-06	0.342	2.2366E-05
0.26	1.2232E-05	2.5319E-05	7.3238E-06	0.290	1.7915E-05
0.26	3.0725E-05	3.3838E-05	1.9424E-05	0.516	1.9313E-05
0.25	4.2561E-05	3.3291E-05	2.5025E-05	0.550	2.6499E-05
0.25	3.5874E-05	1.8297E-05	1.5721E-05	0.398	2.2104E-05
0.25	2.2615E-05	1.3460E-05	1.1138E-05	0.410	1.8800E-05
0.25	1.1547E-05	1.4176E-05	5.8320E-06	0.236	2.6447E-05
0.25	9.5047E-06	1.0914E-05	1.1450E-06	0.220	2.3697E-05
0.25	1.4774E-05	1.1428E-05	5.2099E-06	0.249	1.7220E-05
0.25	1.4398E-05	1.7087E-05	1.0658E-05	0.506	2.0521E-05
0.24	8.7821E-06	1.9388E-05	8.7529E-06	0.480	2.2046E-05
0.24	1.2220E-05	2.5041E-05	1.0970E-05	0.452	1.4267E-05
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0.24	1.7061E-05	2.6153E-05	1.6347E-05	0.638	1.9049E-05
0.24	1.8803E-05	2.5088E-05	1.5584E-05	0.520	2.4080E-05
0.24	2.1683E-05	2.3407E-05	1.4896E-05	0.511	1.2828E-05
0.24	1.5150E-05	1.6401E-05	7.2643E-06	0.222	9.4279E-06
0.23	1.5318E-05	2.6487E-05	1.0566E-05	0.303	1.3076E-05
0.23	2.3222E-05	3.5221E-05	1.7907E-05	0.399	1.3724E-05
0.23	1.8856E-05	1.9618E-05	1.0028E-05	0.273	1.7182E-05
0.23	1.4372E-05	8.1683E-06	2.4061E-06	0.049	2.0234E-05
0.23	2.2493E-05	1.0872E-05	7.7477E-06	0.251	1.8892E-05
0.23	2.1047E-05	1.6839E-05	1.2066E-05	0.411	1.6504E-05
0.23	1.4666E-05	1.4974E-05	6.2137E-06	0.235	1.8461E-05
0.22	1.4761E-05	5.4120E-06	-2.0105E-07	0.015	1.7520E-05
0.22	1.0901E-05	3.0846E-06	-1.0614E-06	0.224	1.3363E-05

0.22	8.3282E-06	6.0224E-06	7.4420E-07	0.229	1.5840E-05
0.22	1.0605E-05	6.5774E-06	2.9465E-06	0.140	1.5816E-05
0.22	1.2250E-05	1.1376E-05	2.0748E-06	0.152	1.2486E-05
0.22	1.3356E-05	2.0299E-05	2.8400E-06	0.389	1.2895E-05
0.22	1.4886E-05	2.0426E-05	8.3843E-06	0.551	1.5842E-05
0.22	1.4021E-05	1.7228E-05	1.0374E-05	0.720	2.1259E-05
0.22	1.4906E-05	1.7894E-05	9.0107E-06	0.556	2.3560E-05
0.21	2.3941E-05	1.8939E-05	1.2304E-05	0.479	2.1106E-05
0.21	2.6823E-05	2.1261E-05	1.4317E-05	0.440	1.7718E-05
0.21	2.3597E-05	2.7104E-05	1.5210E-05	0.362	1.0542E-05
0.21	3.2441E-05	3.0836E-05	2.2461E-05	0.504	7.8154E-06
0.21	3.3987E-05	2.1206E-05	1.8635E-05	0.524	1.2832E-05
0.21	2.4426E-05	1.2088E-05	9.7362E-06	0.384	1.6428E-05
0.21	2.0238E-05	1.4790E-05	1.1120E-05	0.457	1.9411E-05
0.21	1.6603E-05	1.7733E-05	1.1953E-05	0.535	1.4962E-05
0.21	1.5603E-05	1.5498E-05	1.0324E-05	0.454	8.0841E-06
0.20	1.3915E-05	1.0722E-05	7.5196E-06	0.384	1.6356E-05
0.20	1.1836E-05	9.9664E-06	6.1670E-06	0.341	2.3384E-05
0.20	1.7650E-05	1.5514E-05	9.5721E-06	0.335	1.5195E-05
0.20	2.0977E-05	2.4709E-05	1.3544E-05	0.362	9.4775E-06
0.20	1.9372E-05	2.9943E-05	1.4829E-05	0.379	1.0073E-05

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13. ABSTRACT

The design, construction and calibration of suitable instrumentation for measuring temperature fluctuations within a few centimeters of the sea surface, surface wave variations, and wind velocity are discussed. Small bead-in-glass thermistors mounted at 2.5 and 5 centimeters above the water surface were used to measure temperature variations under varying wind conditions and spectral densities computed on a digital computer. Spectra, co-spectra and coherence squares from 0 to 5 Hz are presented.

14. KEY WORDS	LINK A		LINK B		LINK C	
	ROLE	WT	ROLE	WT	ROLE	WT
Temperature Fluctuations						
Air-Sea Interface						
Thermistor Measurements						
Temperature Spectra						
Wave Spectra						